HYDROSYSTEM OPERATION IN COMPETITIVE MARKET: A SYSTEM DYNAMICS APPROACH

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ABSTRACT

A hydroelectric generation plant is a device that converts the potential energy of water streams into electricity. Its dynamics is determined partly by the streamflows and partly by the electricity demand. Physical feedback loops exist between storage head, outflow and production characteristics of hydro plants.

The operation planning of hydroelectric systems is usually done with the support of simulation models, some of which are aggregate, whereas other are detailed, representations of the hydrosystem. All simulation models share the following objectives:

- They seek the optimum operation of the hydrosystem;
- They don't take into account the managerial aspects of the production process.

The last aspect is getting increasingly important in Brazil and many other countries with high hydro participation, due to privatization and unbundling of electricity utilities. In this new market structure, potential conflicts between the optimum operation of the overall hydrosystem (as determined by an independent system operator) and the commercial targets of the individual plants (as defined by the plant manager) may emerge, whenever the plants in a hydro basin belong to different generation companies.

As a consequence, a need exists now for simulation models able to consider, simultaneously, the physical and managerial aspects of the hydropower production process.

In this context, this paper present a SD based, detailed simulation model aimed at determining the hydro operation policies that reconcile the global and local interests in hydropower production. It does so by creating a feedback loop between the production process and the manager's decisions.

KEYWORDS

Operation Systems, System Dynamics, Competitive Market.

1.- INTRODUCTION

The basic function of a power plant, from the technical viewpoint, is the supply of power to consumers at an attractive cost and with an acceptable quality in accordance with the standards prevailing in the electric sector. This requires defining the criteria governing the quality of the service, and analyzing its operational performance. The reliability analysis provides these performance parameters in the form of indexes for the equipment and the plant itself.

In the case of hydroelectric power plants, the performance indexes depend on the scheduled shutdowns of the generator units, on the inflow and quantity of water stored in its reservoir and on the failure rates of the main equipment. The quantity of water stored depends, in turn, on the inflow history, on the environmental conditions, but mainly on the operating policy and on the evolution of the demand. Therefore, to analyze the technical performance of a hydroelectric power plant, it is necessary to simulate the operation of the associated system, considering diverse hypotheses for these variables.

2.0.- DYNAMIC BEHAVIOR OF THE SYSTEM

Basically, in the operation of the hydroelectric system, in competitive market, a couple of functions present dynamic behavior.

The first is associated with the dynamic variation of the reservoir to attend the demand and the minimum downstream level of the river determined by the requirements of other uses, such as navigation and/or environmental considerations. Therefore, the reservoir should vary between the maximum and minimum levels, and between these two levels the demand could be attended, taking into account the restriction of the unit available for generating.

The second dynamic behavior is provided by the strategic decision adopted by the managerial structure of the company concerning levels and functions in the hydro plant and that influences the capacity or level of generation. With regard to this dynamic behavior, it is possible to formulate hypotheses dealing with the variation of the technical and/or strategic parameter and to analyze its consequence.

The figure 1 illustrates a causal diagram for both dynamic variations described above. In both cases, the feedback is due to the variation in one of the parameters or function affecting the other one.

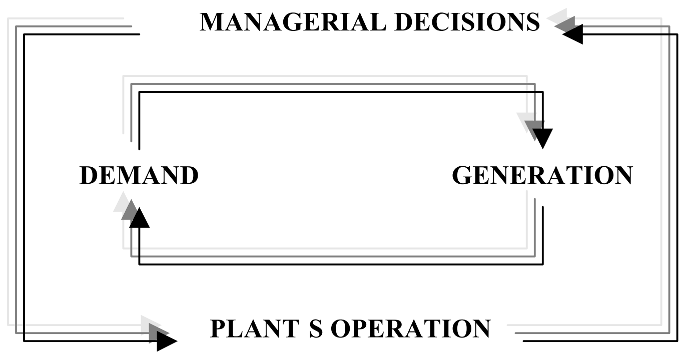

Figure 1 Dynamic behavior in hydroelectric systems operation

3.0.- RERERENCE MODE

The reference mode is a "target pattern" of behavior that the model is expected generate [1]. As the model will consider the capacity of the plant to attend the demand take into account the evolution of the water stored in the reservoir, the model considers the variation of the volume of water in the reservoir as a reference mode.

Therefore, the reference mode varies from an initial value of the volume of the reservoir to either the maximum or minimum limits of the reservoir.

4.0.- MAIN CAUSAL DIAGRAMA

The figure 2, below, illustrates the main causal diagram of the model. In this diagram it is possible to see the linking and polarity that exist between the principal variables involved in determining of the water stored into the reservoir and the average power produced by the hydroelectric plant.

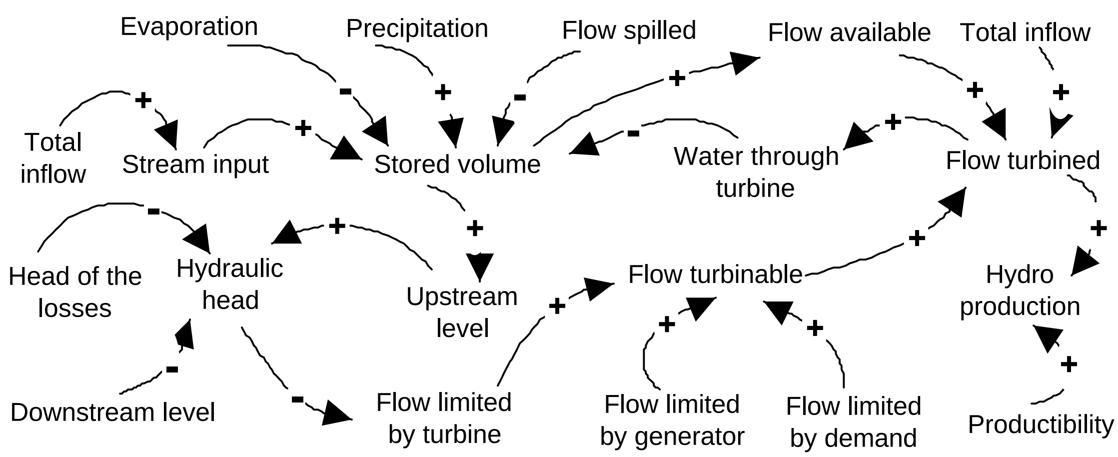

Figure 2 Main Causal Diagram of the Hydroelectric Power Plant

5.0 SYSTEM DYNAMIC DIAGRAM

The system dynamic diagram will show the stock, flow and variable relationships between the variables of the model that permit simulating the operation of the hydro plant. The total model is very extensive, and it will therefore only be possible here to show the main part of the model.

Figure 3 illustrate how it is possible to determine the dynamic relations between the main functions of the model. The *water in reservoir* is selected as the stock variable because the volume of water in the reservoir acts as a storage variable. Also, *water in reservoir* is where the accumulation takes place in the system.

Evaporation, precipitation, stream input, spill flow and water through turbine are the flows that directly affect the volume of *water in reservoir.* The *evaporation* and *precipitation* are the reservoir's surface area multiplied respectively by the *evaporation rate* and *precipitation rate.*

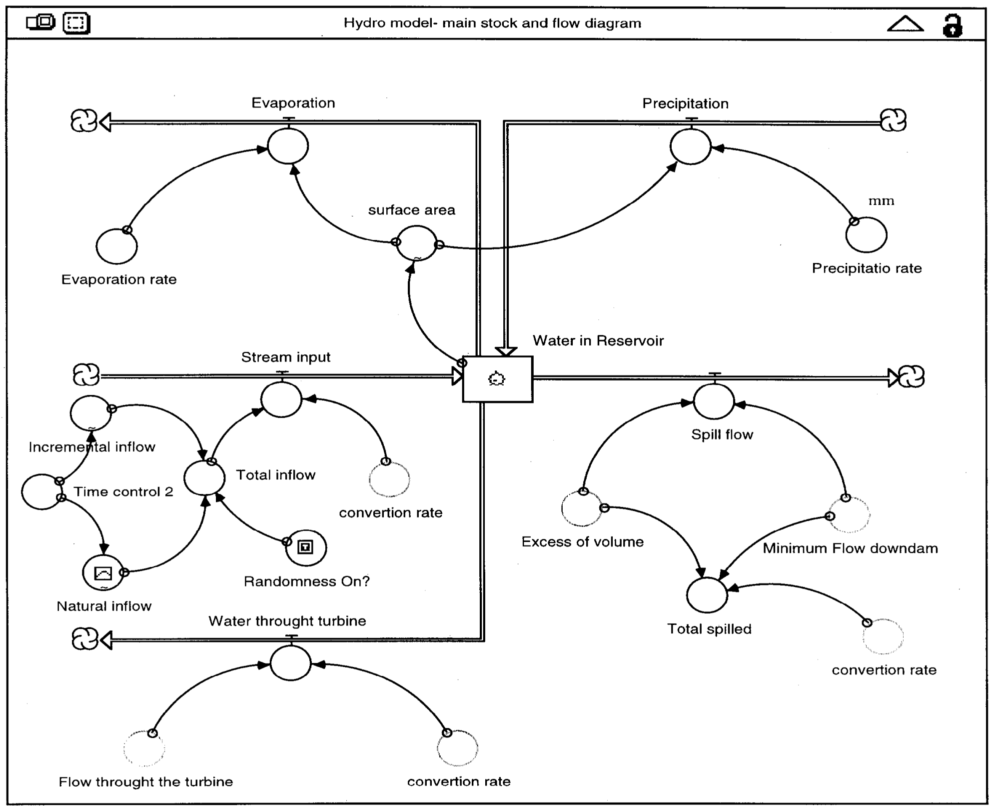

Figure 3 Flow diagram for hydroelectric model

The *stream-input flow* is the sum of the *natural inflow* plus the *incremental inflow*; if the hydro plant is the first of the basin, the incremental inflow is made equal to zero. And if the hydro plant is the second or more downstream of the basin, the natural inflow is made equal to the flow out of the dam of the hydro plant upstream.

The *spill flow* is the sum of the *excess of volume* plus *minimum flow downstream of the dam.* To determine the excess volume it is necessary to compare the maximum volume of the reservoir with the actual water stored plus the total inflow and plus the flow through the turbine. And for determining the minimum flow out of the dam is necessary to verify the flow available in the reservoir and compare the minimum flow with the flow through the turbine.

And finally, to determine the *water through turbine* it is necessary to combine the desirable flow through the turbine and to compare this flow with the flow able to be drawn from the reservoir. The flow able to be drawn from the reservoir is the sum of the total inflow plus the difference between the actual volume and the minimum converted inflow.

5.1 Inclusion of the maintenance schedule

The maintenance is scheduled with use of the *leveling reserve method* that for an independent generating plant can be easily determined through the comparison of the installed capacity with the demand contracted. The inclusion of the maintenance schedule in the model is made through the use of a variable called *maintenance schedule* whom indicate the periods with forecast unit out for maintenance.

For each new time step the model verifies if there is a unit in maintenance, and if there is, the number of units available for generating is adjusted.

5.2 Determination of the LOLP and EPNS

For the determination of the stoichiometric parameters, the designed model uses the approach given in the traditional literature, see for example [6]. The determination of both parameters into the main model is made as follows: the *LOLP* is determined from the *function density of probability accumulated* given for the two conditions, with and without unit retired for maintenance; and the *EPNS* is determined, in similar fashion, from another graph that shows the *EPNS* as function of the *demand*.

5.3 Variation of the Demand

The model permits two different alternatives for analyzing of the growth of the demand, first if the price charged by the plant remains stable, and the demand shows an exponential growth. But if the price also increases, the demand is retracted and this is represented in the model by the price elasticity of the demand.

The price elasticity of the demand shows the sensitivity of the demand to price variation. Mathematically, if ***D*** is the demand and ***P*** is the price, the price elasticity of demand is given by:

$$h = [-dQ/dP] \, . \, [P/Q] \qquad (1)$$

In the model a *reference price* is given, in $ per kWh, and the *actual price* recovered by the plant, is also given 1(one) as an initial guess of the reference elasticity.

6.0 COMPUTER SIMULATION

The model was implemented by means of Stella software and with describes how it can be used to analyze the variation of hydro parameters. Other applications of the model are indicated in the reference [2]. The result presented in the following was obtained by short time simulation; to obtain results over a long time, only the planners need rerun the model for the time they like.

6.1 Verification of the Reference mode

In order to verify if the model gives the reference mode specified in the item 3, and to show the importance of the initial value of the reservoir level, the model was run for 24 months with the same demand for four different initial values. The results obtained are summarized in the figure 6.

In the figure 4 above, the curve 1 represents the evolution of the reservoir level from the initial value equal to the maximum value and the curves 2 to 4 represent the reservoir level evolution from different initial values. Here it is possible to see the “target pattern” of behavior that the model was expected to generate.

If, for example, the curve number 2 is analyzed the initial value for the reservoir level was assumed to be less than the maximum value, so as the upstream flow feeding into the reservoir in the firsts period are grater than the flow necessary to attend the demand, the additional inflow will be stored in the reservoir.

The first three curves reach the maximum value for the reservoir level, this pattern is because the demand increased to less than the maximum capacity of the plant. In other side, the four curve fell to the minimum value of the reservoir because the maximum capacity of the plant was exceeded.

The figure 4 below, shows the demand (curve 1) and the generation of the plant (curve 2) for the last condition of the figure above.

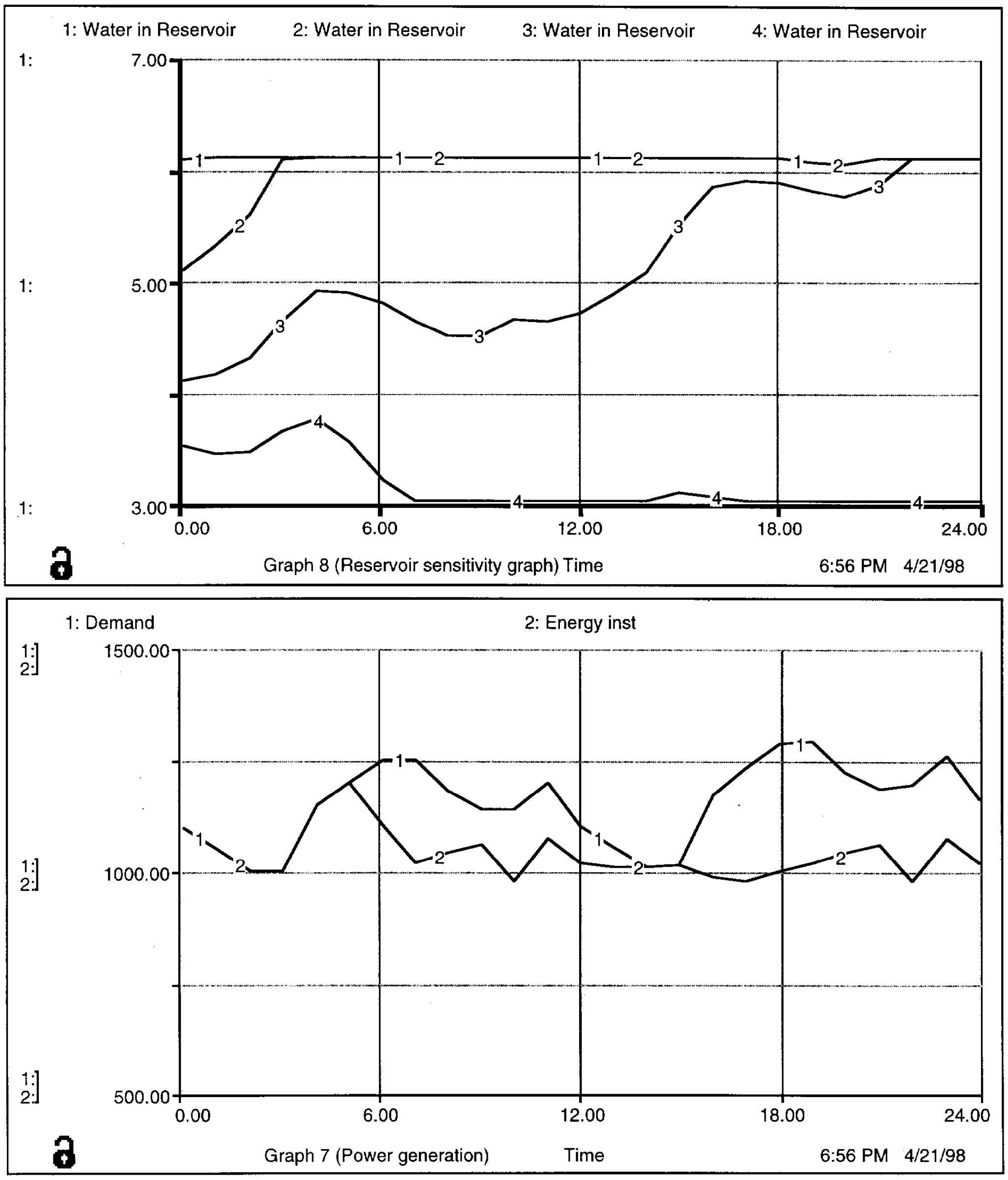

Figure 4 Reservoir initial value sensitivity graph

Finally, from this and other results (not showed here), it is possible to conclude that the model result and the “Target pattern” behavior are very closed

6.2 Polities test and random parameter analysis

In order to test polities and analyze parameters that can vary randomly over the time, the model includes two panels' control: *The Main Panel Control* and *The demand-Price Panel Control* . With the firs panel control the user can make individual or combined tests for:

- Different hypotheses over *the natural and incremental inflow,* this is particularly important for the second, third, etc. plant of the same basin.
- Different policies for maintenance schedule.
- Different initial value of the reservoir level.
- And, can also apply randomness over the natural inflow.

With the *Demand-Price Panel Control* the user can also make individual or combined test for:

- Different demands contracted for the first year.
- Different demands-growth rates.
- Different price elasticity's of the demand.
- Different reference prices.
- Different actual prices per kWh.
- And can also fix the maximum demand of the plant.

Both panels' control were designed to rum over 120 months with a partial stop every 24 months. At each stop, the user can apply news hypotheses over the polities' parameters.

7.0 TWO OR MORE HYDROELECTRIC PLANTS IN THE SAME BASIN

To extend the preceding model in order to simulate the operation of the two or more hydroelectric plants in the same basin, it is necessary to add at least three main considerations:

- First, that the model can be applied to analyze competitive markets, so for each different plant it is necessary to have an individual model.
- Second, that the electric market is common for all plants, so in the market share model, it is considered that the demand lost for one hydro producer is gained by the others. The loss and win of the demand is defined by the hypotheses made on the price elasticity of the demand.

- It is necessary to take into account that the flow into the reservoir of the downstream plant is the sum of the flow out of the reservoir upstream plus the incremental flow.

8.0 CONCLUSION

The analysis presented in this paper shows how is possible with the System Dynamic approach to build adequate models for hydroelectric plant, and also how to use it to analyze of managerial decisions.

The different sensitivity analysis permits us to conclude that the model showed as "robust".

The policy analysis through the different control panels proved to be very simple, so it can be adequate for use by an expert planer who is not of the electric area.

Finally, the extension from one plant to two or more plants in the same basin can be made in very simple form only it is necessary to add plant and establisher rule for the market share. This last point is at the present object of research in the *University Federal of Santa Catarina*.

9.0 REFERENCES

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APPENDIX 1: Control Panels for Policies Test and Random Parameter Analyze